Experiments with Compressed Air

... BY ...

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THESIS

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

Stanislav Dowiatt

ENTITLED Experiments with Compressed Air

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE

OF Bachelor of Science in Mechanical Engineering.

L. P. Breckenridge

HEAD OF DEPARTMENT OF Mechanical Engineering.

Historical Review of the Uses of Compressed Air.

The first authentic patent for compressed air machinery was taken out in England in 1726 by Rowe. (James Steel. Engineer, London vol. XLI., p. 473). From that time up to the beginning of the 19th century there were many attempts to pump water by means of slightly compressed air.

In 1799 George Medhurst took out a British patent to compress air for motive power by means of a windmill, and in 1828 Bompas in a provisional British patent #5694 proposes to propel locomotives by compressed air. Also in the same year, it is believed, that Colladon proposed to Brunel to employ compressed air in the Thames tunnel.

However the first decided advance in the science of compressed air and its application was made by Wm. Mann. In his patent (British # 5797 of June 1, 1829) he states that by application of compressed air, power and motion can be communicated to fixed machinery, carriages, locomotives and ships. In the description of his method of compressing air, he says: "The condensing pumps used in compressing the air I make of different capacities, according to the density of the fluid to be compressed - those used to compress the higher densities being proporionally smaller than those previously used to compress it at the first or lower densities" etc. It is evident from this extract that Mann discovered the advantage of compound compression.

In 1836 James Surrey in British patent suggests portable vessels filled with compressed air for the use of railways; he also suggests central compression plant with a system of piping between stations.

In 1844 Arthur Parsey in British patent patents a regulating device between the receiver and the cylinder.

In 1847 Von Rathen in English patent describes the process of wet and jacket cooling; he also describes a refrigerator for cooling the air after compression and also a reheater.

In 1852 Colladon applied for an Italian patent for the use of compressed air as a power for driving the rock drills in tunnel construction.

Jan. 15, 1854 Arthur Parsey patented in England a double acting air pump with hollow piston and rod, through which air is admitted. The valve may be as large as the cylinder. The rod passes through the valve and has a spiral spring to keep the valve seated.

In 1864 John H. Johnson took out British patent on working piston and cylinders by compressed air, expanded by heat before entering the valve box, employing a portion of the power in forcing fresh air into the main receiver. The working piston rod carries a second piston working in an air pump and forces air into a receiver with three valves, of which one of them opens the air passage when the pressure decreases, and shuts it when the pressure is sufficient. The second is a safety valve, and the third is acted on by the engine governor.

The above summary of the most important improvements is intended not only to point out in a slight degree the uses of compressed air, but also to illustrate the development of air compressor machinery.

Almost all of the material contained in the above paragraph is taken from Drinker's Treatise on Explosive compounds.

Modern Methods of Compression.

It will be maintained in this paper that the modern compressor is as it is represented by the compressors built at the present time in this country by the prominent builders. This will at once exclude all the "wet" and hydraulic compressors, also compressors operated by cranks, and in general all compressors, which although feasible from thermodynamic standpoint are not practical mechanically.

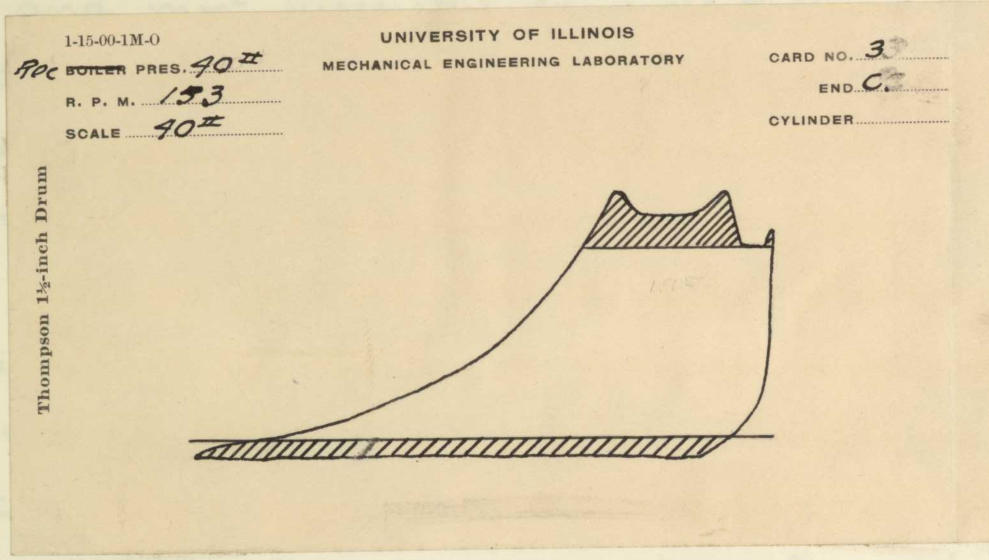
Modern compressors are therefore divided into single and multiple stage compressors. These two classes may be divided into horizontal and vertical.

The advantage of multiple over single stage compressors will be discussed in the paragraph on thermodynamics of compressed air.

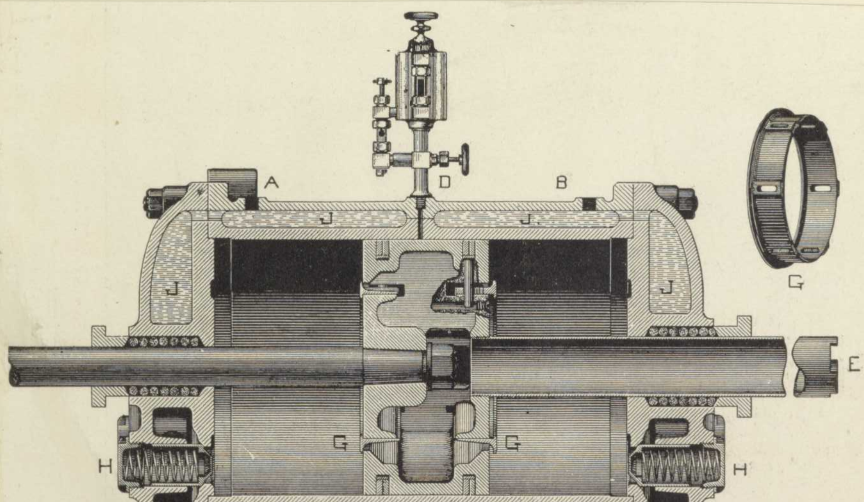
It is the personal opinion of the writer, shared most likely by the majority of engineers, that except for very large machines, which take much of the valuable space, the horizontal compressor is to be preferred. All the elements of discussion of the relative virtues of horizontal and vertical steam engines apply to the air compressors; besides spring valves in compressors can be better distributed in horizontal than in vertical machines; the stroke in horizontal compressors can be made proportionately longer than in vertical, thus minimizing losses due to clearances; and also circulation of cooling water can be better distributed.

Compressors are often classified according to the method of governing the amount of air compressed. There are many ways of doing this. The first and most common method in direct connected compressors is to automatically throttle the steam, thus reducing speed of the engine and diminishing the amount of air supplied to the receiver. Such device is used on great majority of medium sized machines. Second, by an automatic unloading device by means of which when the pressure in the receiver reaches certain point, a communication is automatically opened between both ends of the compressing cylinder, thus while the compressor is running as usual it is not doing any work. This method is extensively used on small and medium sized machines, and also belted compressors. Another method is to have a belt shifting device as adopted by the Rand Co. on their small compressors. Such compressors have two pulley wheels, one of which is loose. When pressure reaches its desired limit, an automatic belt shifter pushes the belt over to the loose pulley, thus stopping the machine. This method is open to the same objection as the previously mentioned unloading device; that is, the load is thrown on and off at once, causing bad strains in compressor and belts. Considering that such compressors usually run at comparatively high speeds of about 150 revolutions per minute, the belt shifting device is the more objectionable of the two, because each time compressor starts up, not only the full load, but the whole resistance of starting the heavy machine at full speed is thrown instantly on the belts. Another objection to these two methods is that the pressure in the receiver does not remain constant.

Compressors employing the three methods of regulation previously mentioned use simple poppet valves throughout. Such valves generally are not altogether satisfactory for the following reasons: First, - springs become unreliable with age; Second, - they are noisy; Third, - they offer considerable valve resistance as will be shown by the accompanying card taken from compressor using poppet valves.



Another valve arrangement, which is claimed to give a good deal of satisfaction is Ingersoll Sergeant Co's piston inlet and poppet outlet arrangement. It is illustrated by the accompanying cut from I-S. catalogue.



DETAILS OF PISTON INLET AIR CYLINDER.

A.—Circulating Water Inlet. D.—Oil Hole for Automatic Oil Cup. G.—Piston Inlet Valves.
B.—Circulating Water Outlet. E.—Air Inlet (through piston inlet pipe). H.—Discharge Valves.
C.—Water-Jacket Drain Pipe. F.—Air Discharge (showing flange). J.—Water-Jacket.

It is the tendency lately to substitute mechanically operated valves in compressors for the poppet valves. The best and most successful example of this method is illustrated by the "Variable volume", constant speed compressor, invented, patented, and manufactured by Mr. Edward A. Rix of San Francisco, Cal.

It is especially imperative in California and other localities where so many compressors are driven by electricity that the speed of the compressor remain constant, whatever the load, more than that, the constant and sudden switching off and on of the load has a bad effect on the current generating mechanism at the central plant and upon the lights. In such places, therefore, it is necessary not only to run the compressor at constant speed, but also to have a sensitive governor, adjusting the load to a small variation of pressure in the receiver, thus assuring smooth running.

The following are extracts from Mr. Rix's pamphlet "Some recent compressed air machinery" also

American Machinist Nov. 10, 1898,

Mining and Scientific Press Dec. 31, 1898.

Iron and Coal Trades Journal Nov. 25, 1898.

"...The ideal compressor to properly overcome the objections and difficulties before mentioned is one, which will automatically cut itself out by increments as the demand for air decreases, and when demand for air ceases it will have cut out the entire machine and will as automatically decline to deliver air when occasion demands and gradually restore the delivery of the full volume, if such be required. All this is done in the most gradual manner, covering such a period of time that it will not interfere with the harmony of the electrical installation.

This cut out device must be so constructed, that it can be instantly and conveniently operated for starting the compressor. It will be readily seen that this must be accomplished by constructing such a valve mechanism that will deliver from the cylinder the whole of its contents or any portion that may be desired. In other words, the cylinder and the valve motion will be capable of delivering a variable volume when running at a constant speed and constant stroke.

This I accomplish by so constructing and operating compressed air engines of the double acting type that the volumetric capacity of the cylinder can be varied by changing the point of closing of the induction valves in respect to the stroke of the piston, so as to entrap and compress the volume of air required for use and no more, thus producing a constant pressure and variable volume, while the piston is moving at a uniform speed and range.

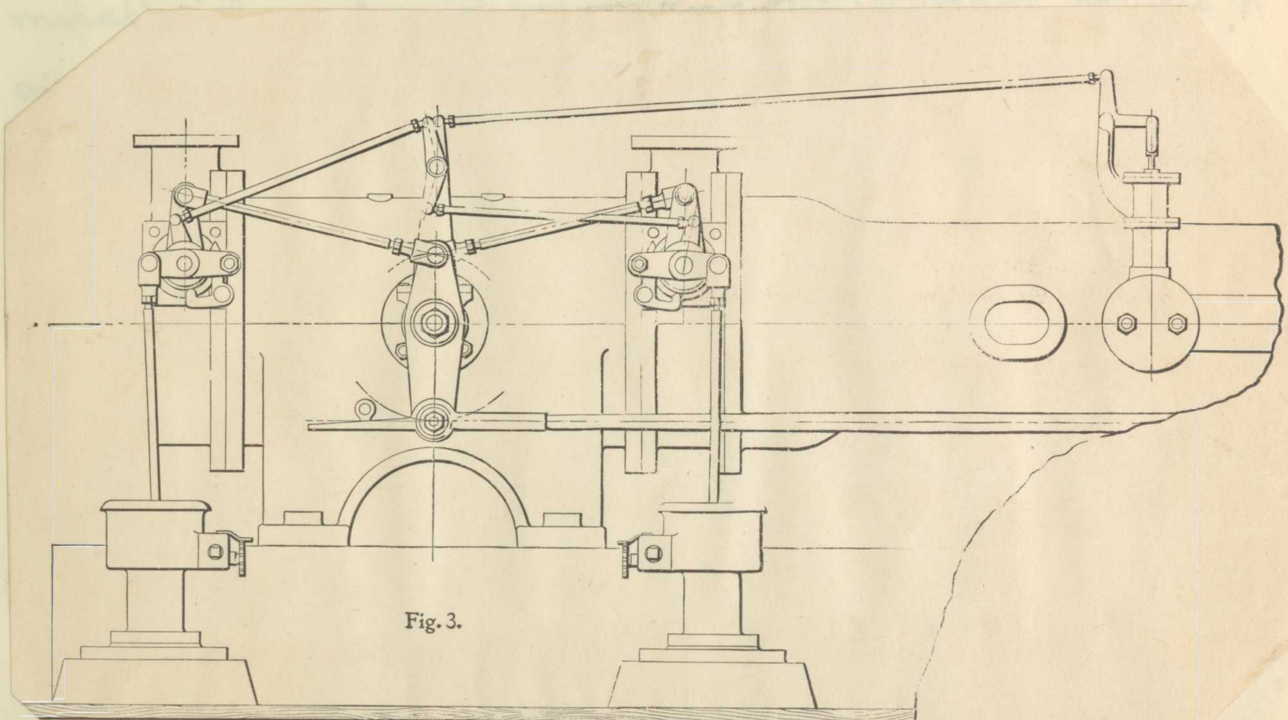
The valve motion which I employ is under control of a governor having a relay attachment after the plan of the Hunning valve motion, which permits any change of the valve motion to be made in degrees of such magnitude that a short time or very considerable length of time may be employed to make a complete change in the operation of valves. This enables me to avoid any sudden changes of load on the electric motor which drives the compressor, and there will be no disturbance of the transmission line nor the lights that may be attached thereto.

The inlet valves themselves are of the Corliss type, with dash pots attached similar in almost every way to the Corliss valve and dash pots and trip mechanism for steam engines, with this exception, that the Corliss steam hook is tripped on its upward motion cutting off the steam at any point of the stroke up to one half, whereas in the valve motion which I employ there is no tripping of the hook on its upward course, the tripping taking place at the very top of its stroke, or on its downward course.

The eccentrics are practically set with the crank instead of at right angles, an angular advance being merely to cover the lap of the valve. This makes the hook travel from the bottom of its stroke to the top during one stroke of the piston. If I desire that the cylinders shall compress no air, the hook instead of being tripped at the top of the stroke, still retains its hold of the valve stem and the dash pot, and follows back during the return stroke of the piston, leaving the valve open. The air is then gradually pushed out of the cylinder into the atmosphere again. If, however, I wish to compress the full contents of the cylinder, the valve hook is tripped off at the top of its stroke coincident with the end of the stroke of the piston. If I wish to compress half the cylinder volume of air, the air is drawn into the cylinder and gradually pushed out again on the return stroke, and the valve is tripped at half stroke, and so on at any intermediate point.

There are many methods of operating the trip hook. One method which I employ is very simple. It consists merely of introducing on the tail end of the Corliss hook one extra pawl and spring which on the upward motion will pass the trip cam, but on the downward motion rises on the cam and throws off the hook.

For small single acting cylinders I employ a different device, and do not depend upon the induction valves at all for regulating the amount of air which the cylinder shall contain, but actually shorten the working length of the cylinder by sliding back and forth with the proper device which is under the control of the governor and the air receiver, a section, or stave of the cylinder itself. This section or stave is simply a long slide valve, scraped to its seat, which is a portion of the cylinder itself, about two inches wide in a cylinder about ten inches in diameter. When the slide is entirely moved out, the cylinder has an opening through its entire length, so it naturally cannot compress any air, but as the slide is gradually pushed in, it slowly



GENERAL ARRANGEMENT OF VALVE MECHANISM FOR VARIABLE VOLUME COMPRESSOR.

closes the cylinder from zero to full length. The slide can be stopped at any length, and the cylinder thus be made stationary at any desired length, and thus the machine be a fixed compressor for any capacity from zero to full capacity.

The accompanying indicator card shows most admirably the action of valves and the resultant volume of air compressed.

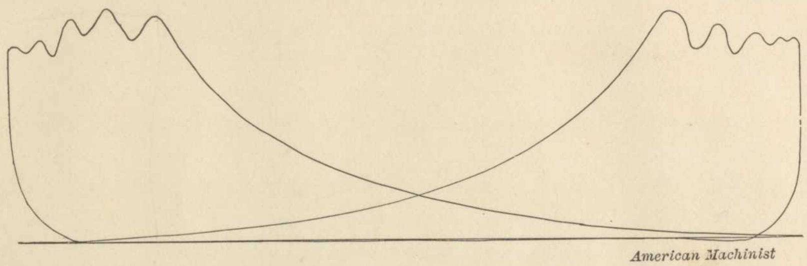


Fig. 2

CARD FROM 15x30 COMPRESSOR, WHILE COMPRESSING FULL VOLUME.

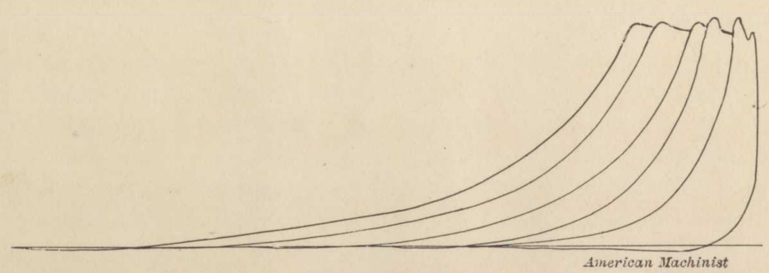


Fig. 3

CARD FROM 15x30 COMPRESSOR SHOWING VARIABLE VOLUME

The card #2 is taken when compressor delivers full capacity and #3 consists of five different cards working at from full capacity to only a fraction of the normal. In making of computations of cards in #3 it must be remembered that they are all of different length. The right hand, or delivery ends of the cards are of course coincident, but the compression in each case begins at the point where the compression line begins to rize above atmosphere line.

The compressor operates to perfection, the dash pot cutting off as nicely and clearly as in any Corliss steam engine, and there never has been in either of the two machines of this type now in operation any air ever delivered out of the safety valve of the receivers. The variations of pressures are very slight, being all between 90 and 94 pounds. The areas of the inlet valve openings are from 8 to 10% piston area".

Reheating the air before using it in an engine

Since the work done by any intermediate substance depends upon its range of temperature in expansion, it will be seen that by having air as hot as possible before it enters the cylinder, and being exhausted as cold as possible the greatest efficiency will be obtained.

There are great many reheaters for this purpose on the market. Most of them are small furnaces containing passages through which compressed air passes and is reheated.

Mr. Rix describes in Am. Mach. March 30, 1899 a method of reheating, which he uses in one case. The air at 80# pressure, which finally drives a 75 H.P. hoisting engine is lead in an independent pipe down through a steam drum of a 50 H.P. boiler, through one of the boiler nozzles to within about 3 inches of the surface of water, allowing the air to impinge upon the surface of water and spread out giving it in that way an ample opportunity to absorb the heat and moisture. It is found from actual results that it takes about eight cords of wood per month to do the heating, which is about quarter of a cord of wood per day. This wood is mountain pine and it possesses a power capacity of about thirteen H.P. per twenty four hours with ordinary slide valve engines. From the small amount of wood used it will be noted that there is no active firing done under the boilers, merely enough fire being introduced to maintain itself. Three or four sticks of wood placed on the fire every four hours are enough. The feed pump is called into service once or twice every twenty four hours.

It may be thought that there is some danger in mixing the air with the steam, but there is none. The air valve has been opened establishing connection between the receivers and the boiler when there was 90# steam pressure on the boiler with no vibrations or injurious effect of any kind.

Modern Uses of Compressed Air.

It is of course absolutely impossible to name all cases where compressed air can be employed to do useful work to better advantage than other motive powers. It may be, however, broadly said that compressed air possesses great advantages over all other sources of power for all under-ground work. There its advantages are: Lack of loss due to condensation and consequent heating of underground temperature; when we consider that often power is to be transmitted by pipes for several thousand feet, and also from nature of the work there generally is no pipe covering to speak of, or if there is, the cost of it,- the balance in favor of compressed air on this point alone is considerable. Furthermore exhaust from air-operated tools is of very considerable assistance in ventilating such places, while on the other hand exhaust steam in underground work, to say the least is very undesirable. Also the case of bursting of a pipe is much more dangerous in the case of steam than that of air. Advantages of compressed air over electricity is avoidance of all dangers peculiar to electricity, especially when handled by incompetent hands, and much greater simplicity and general ruggedness of air motor over its electric competitor.

Air power possesses peculiar advantages as a commercial article in cities, where it is piped to individual consumers from a central plant. Its application and advantages can be best illustrated by some extracts from Mr. Alexander B. W. Kennedy's "Compressed Air" He says:

"...I have already mentioned the great convenience and handiness, which a compressed air motor possesses. From the engineer's point of view these qualities are most striking. The engine starts, for instance without the least hesitation even with the full brake load on directly the valve is opened if the crank is just past the center. This, of course, is impossible with a gas engine, and hardly less impossible with any single-cylinder steam engine. The absence of the heat and leakage and of the noise and smell which so often in greater or less degree accompany smaller steam and gas motors constitute a very much larger difference than could at first thought to be possible. But from the consumer's point of view the advantages are even greater than from the engineer's. There is first of all the complete absence of danger and nuisance of every kind. There is then the great saving of space, even as compared with a gas engine, and much more as compared with a steam engine and boiler. There is reduction of insurance on account of the entire absence of fire risk. Not only this but the air motors seem to me completely to supply that most important industrial want: a motor suitable for "small industries", that is for work carried on in workmen's own houses, or in very small workshops. For here it is not merely mechanically most suitable, but in the nature of things it can be made to cool or ventilate by its exhaust to any desired extent. The sanitary advantage of this in cases where work is carried on in small spaces can hardly be exaggerated."

Is there any power so well adopted for such places as "sweatshops" in our large cities, where often as many as twenty women and girls are packed in one room, working ten hours at a stretch on sewing machines that are run by a flimsy four horse power engine and boiler, that shakes and trembles with age and longs for the scrap heap, where it belongs. What other power is there so ideally adopted for all the small toy and other innumerable shops that are a shop in the day and living and sleeping rooms at night?

Quoting again Mr. Kennedy: " Even in a very large printing-office in Paris I found an almost unbearable atmosphere made quite pleasant as long as the motor was working by allowing a portion of the exhaust to come into the room.

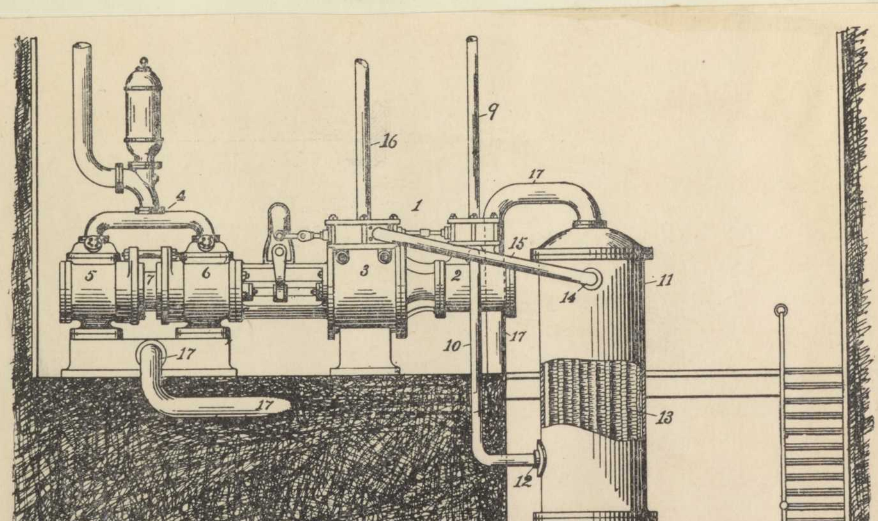
By using air direct from the mains in the motor or by heating it only very slightly, the exhaust air can be of course so greatly reduced in temperature as to be available forn freezing purposes. In one Paris restaurant, for instance, which I visited, I found that the exhaust was carried through a brick flue into the beer cellar. In this flue the carafes were set to freeze, and large molds of block ice were also being made for table use, while the air was still cold enough in passing away through the beer cellar to render the use of ice for cooling quite unnecessary, even in the hottest weather. The nominal function of the engine in this case was the charging of batteries used in the electric lighting of the restaurant. The conjoint use of power and cold is common in Paris, the power being in this case generally applied in electric lighting. While in any large city, such as Paris, it is, no doubt, a great point that by a compressed air system the handiest possible cooling appliances can be brought anywhere within reach, in tropical climates this is something rather of necessity than of luxury. In such cases we might have the apparent paradox of a motor worked essentially for its exhaust:- the work done would be a by-product. In such a case if there were no useful work to be done the motor could even be made (as has been suggested to me) to pump air back into the main, and thus virtually to about halve its air consumption. This possibility of 'laying on' cold air in hot climates, is, of course, a most important matter in connection with the future of compressed air."

In connection with using compressed air in mine pumping, there appeared in Modern Machinery, July '98, and The Collier Guardian, London, August 26, 98 an article by Mr. E. A. Rix of California describing a new device for reheating compressed air, which for its originality and practicability commands attention. The pump and reheater are illustrated by a cut from reprint of the above articles.

Mr. Rix says: "In many places pumps of this character"(ordinary direct acting steam pumps" cause considerable annoyance from freezing, and for this reason compound direct acting pumps cannot be used with cold air... A compound direct acting pump which is heated sufficiently to prevent its freezing will pump twice as much water for the same amount of air as a single acting pump. If a single acting pump will not freeze in working under ordinary conditions, introducing the air into the cylinder we will say at 60° temperature (F), the compound pump will not freeze if the air entering the compound cylinder be brought up to the same temperature...

"A problem which occured to the writer" (Mr. Rix) "was to attempt to run plain compound pumps without any extraneous source of heat by utilizing simply the heat stored in the water being pumped at ordinary temeratures. The result was an installation of a Worthington pump, having capacity of 200 gallons per minute at a lift of 500 feet in the Gwin mine, Calaveras Co., Cal.

The cut accompanying this communication shows approximately the manner in which the installation was made. A 300 HP Wainwright copper corrugated heater was placed in the suction pipe of the pump, the water being pumped passing through the corrugated copper tubes at a temperature from 60 to 70° (F.). The air after being exhausted from the high pressure cylinder at a pressure of about 35# passes into the shell of this re-heater and around the outside of the copper tubes. The extremely low temperature of the exhaust from the high pressure cylinder is thus neutralized, by coming in contact with the water in the copper tubes, while the air is raised to practically that of the water. It then passes to the compound cylinder, does its work, and is exhausted without freezing.



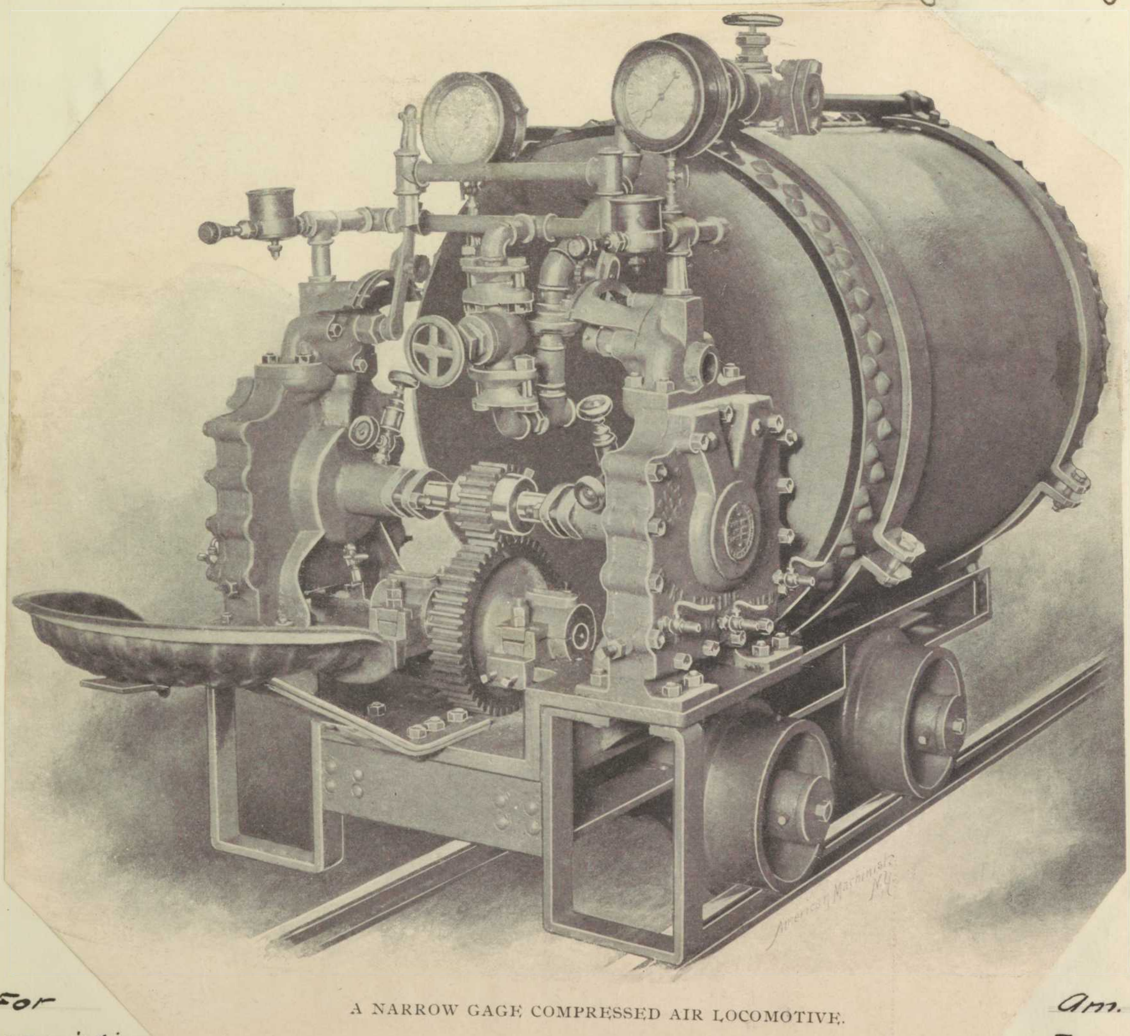
RIX PUMP REHEATING DEVICE TO INCREASE EFFICIENCY.

Before installing this compound pump on the 600 foot level of this mine, a Worthington sinking pump had been used to pump out the water. The compressor furnishing the air to this pump made 55 revolutions to actuate it and to supply the power for a hoist and to overcome pipe leakage. The latter two items taking about 20 revolutions of the compressor, leaving 35 to be used by the pump. When the compound pump was put in place the revolutions of the compressor dropped down to 35, which showed a gain of 50% in favor of the compound proposition with its reheating.

This apparatus can be installed in the discharge pipe or in the tank adjacent to pump when the water accumulates in the mine and can overflow it freely. Morover this is the proper method of applying heat to air used in a compound pump. Many pumps have the air heated before it goes into the initial cylinder, which is economical as far as the initial cylinder is concerned, but by actual observations the writer has found that the clearances between the high and low pressure cylinder are such that the exhaust from the high pressure cylinder loses a considerable portion of its pressure before the stroke commences, and the drop in pressure causes such a drop in temperature of the air entrained between the two cylinders that the virtue of the reheating affects but slightly the compound cylinder where it is most needed.

To be really an economical proposition the air should not only be heated before it goes into the high pressure cylinder, but in the receiver between the two cylinders and also in jackets around the two cylinders. There is no doubt that by doing this reheating properly in compound pumps where steam or highly reheated air is used that the efficiency of this pump can still further be raised 25%.

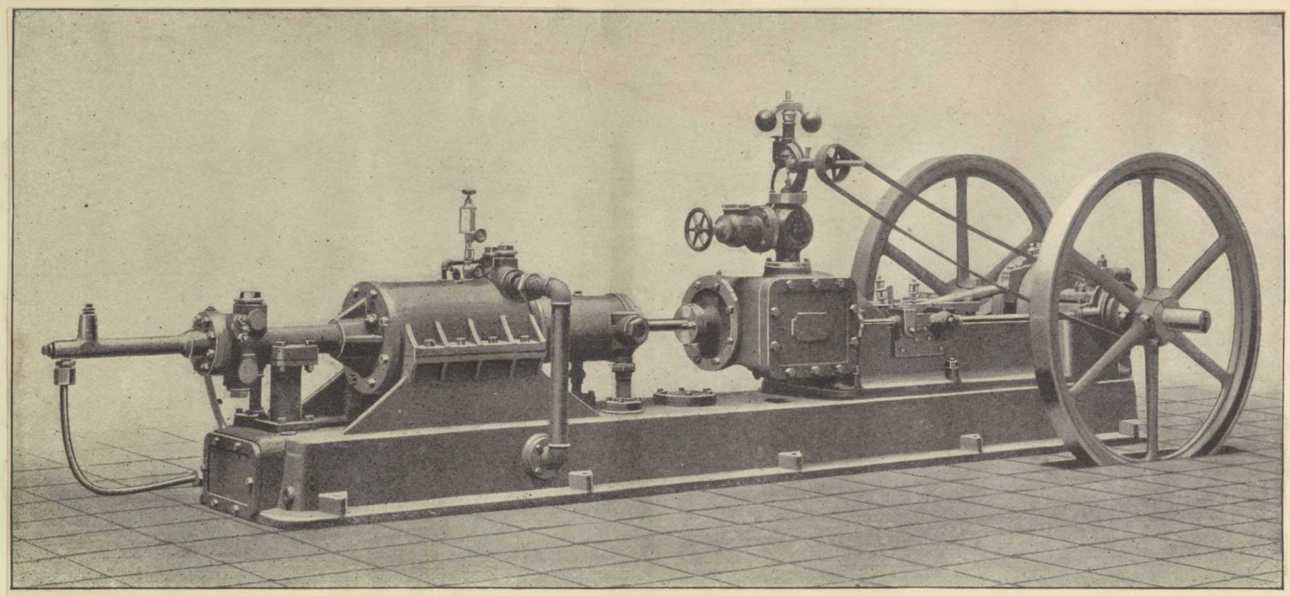
The accompanying cuts represent some of the novel and interesting compressed air tools and appliances, illustrated and described in various engineering papers.



A NARROW GAGE COMPRESSED AIR LOCOMOTIVE.

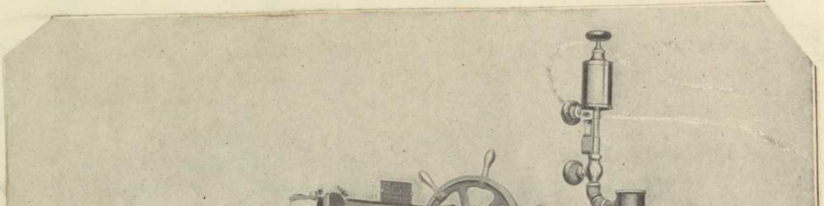
For description see

Am. Mach
Jan. 19, 1899.



FOUR STAGE RIX COMPRESSOR FOR 2500 POUNDS PRESSURE

For description see Amer. Mach, June 15, 1899.



RIX AUXILIARY MINING HOIST.

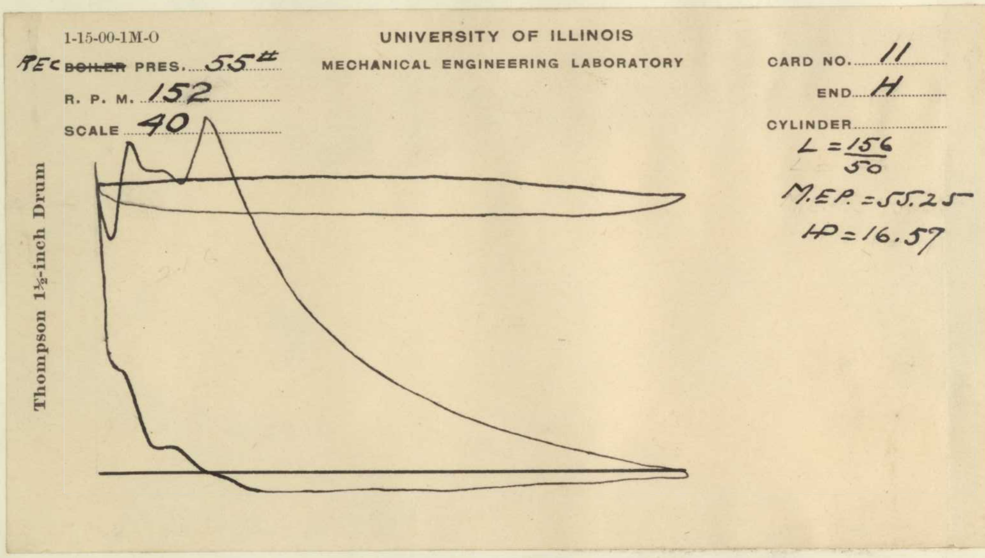
For description see Amer. Mach. Aug 3, 1899.

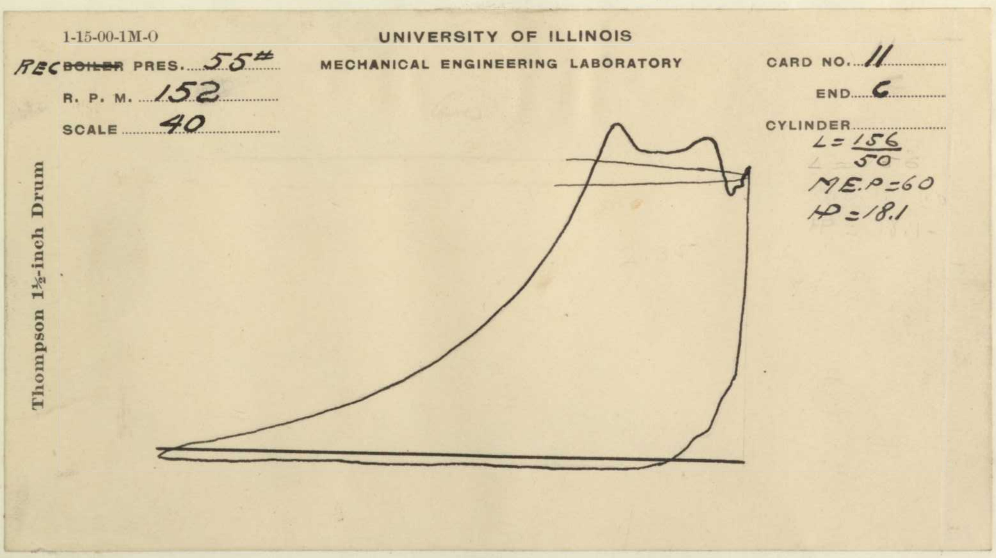
SUMMARY OF TESTS WITH LABORATORY COMPRESSOR.

As found at first the compressor was taking air at 90° F. The indicated horse power required to compress this air to 70# pressure per sq. in in a 10"x10" cylinder was 27.5 HP. Then the intake pipe was extended until it reached outdoors, then thoroughly insulated with hair felt all the way between intake end and the cylinder, and then the compressor was tested again. This time the steam engine developed at the average 30 HP. The amount of cooling water for the compressor cylinder being the same in both cases.

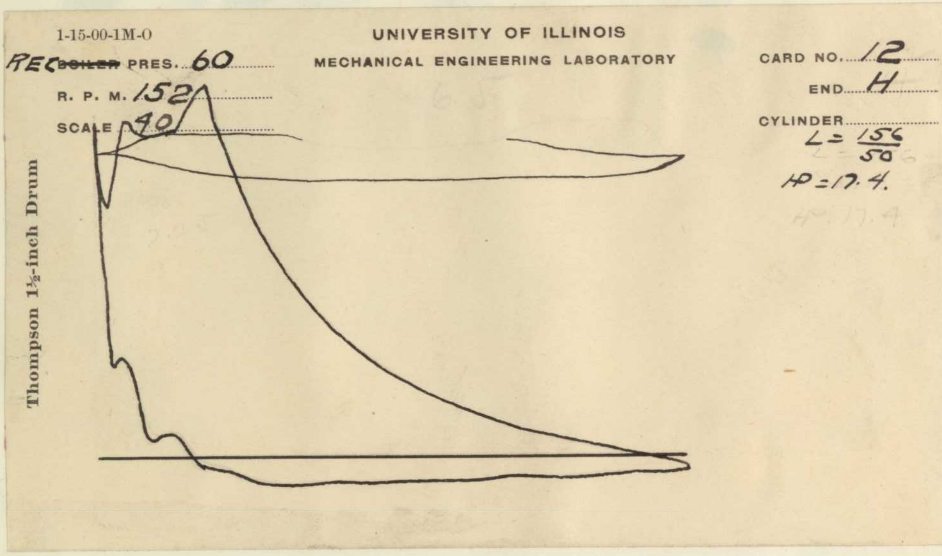
Pressure in the air Receiver	I.H.P. at the engine	Net H.P at the engine.	H.P. computed from air card.
35			13
40			14
45			15
50	25.5	14	16
55			17
60	27	15.5	18
65			18.8
70	30	18.5	

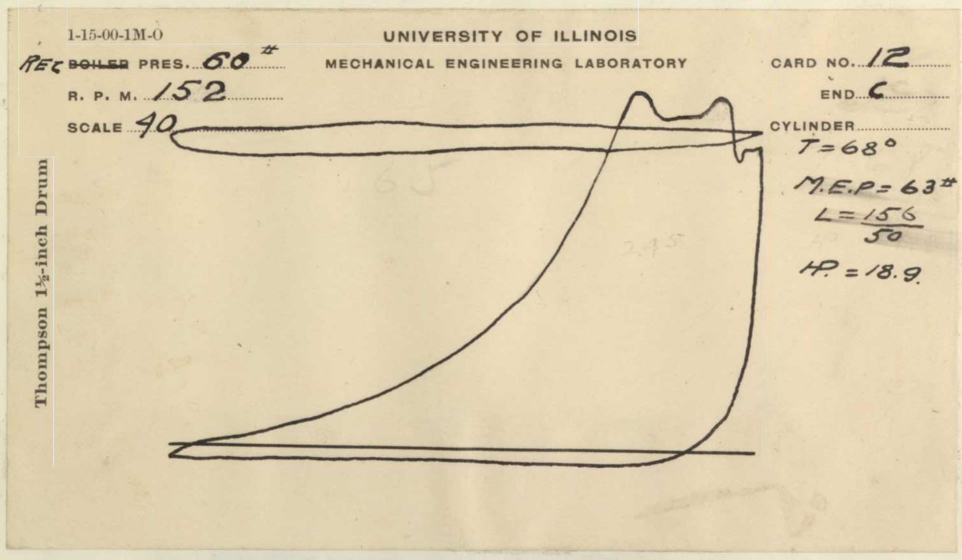
It will be seen that the air compressor develops a little more work than the engine which drives it; that of course is impossible. But as the writer had to do all the work alone, he could not take cards from steam engine and compressor at the same time. Boiler pressure was assumed to be constant 110#, which it most likely did not do, and the revolutions of engine and compressor were obtained by taking the number of revolutions in ten minutes and dividing by 10. The steam and air cards were taken at an interval of several days, the conditions, however, were kept exactly the same on both days as far as is known to the writer.



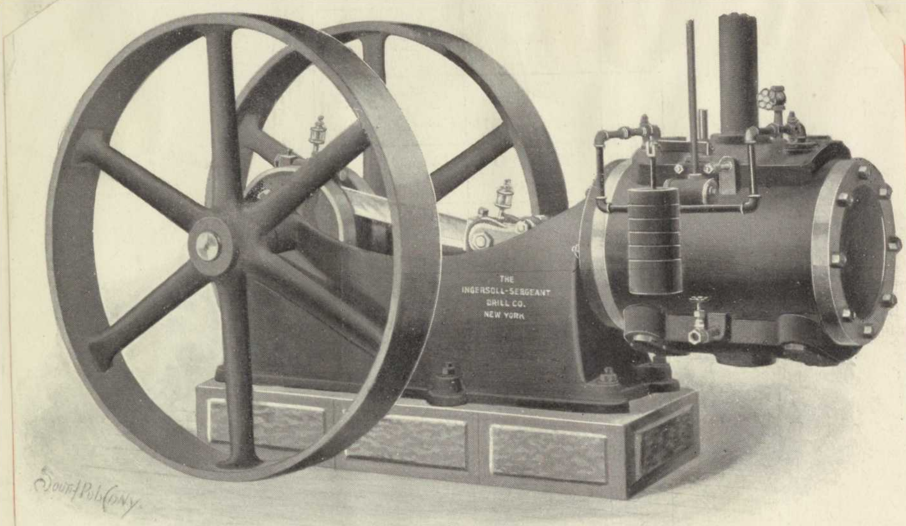


Sample cards from the 10"x10" class E Ingersoll-Sergeant air compressor. M.E. Lab. University of Illinois.

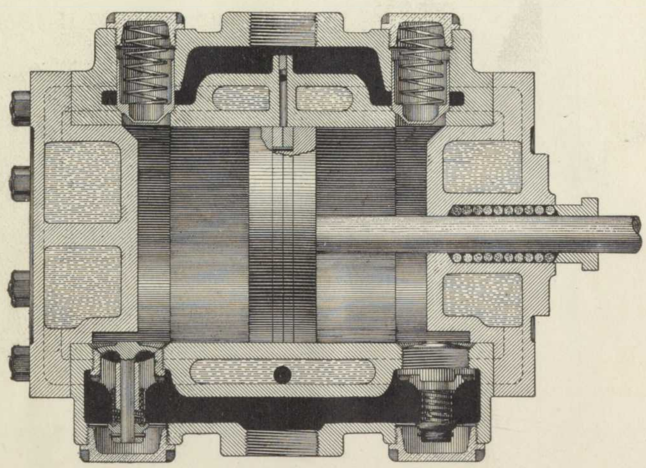




Sample cards from the 10"x10" class E Ingersoll-Sergeant air compressor, M.E. Lab. University of Illinois.

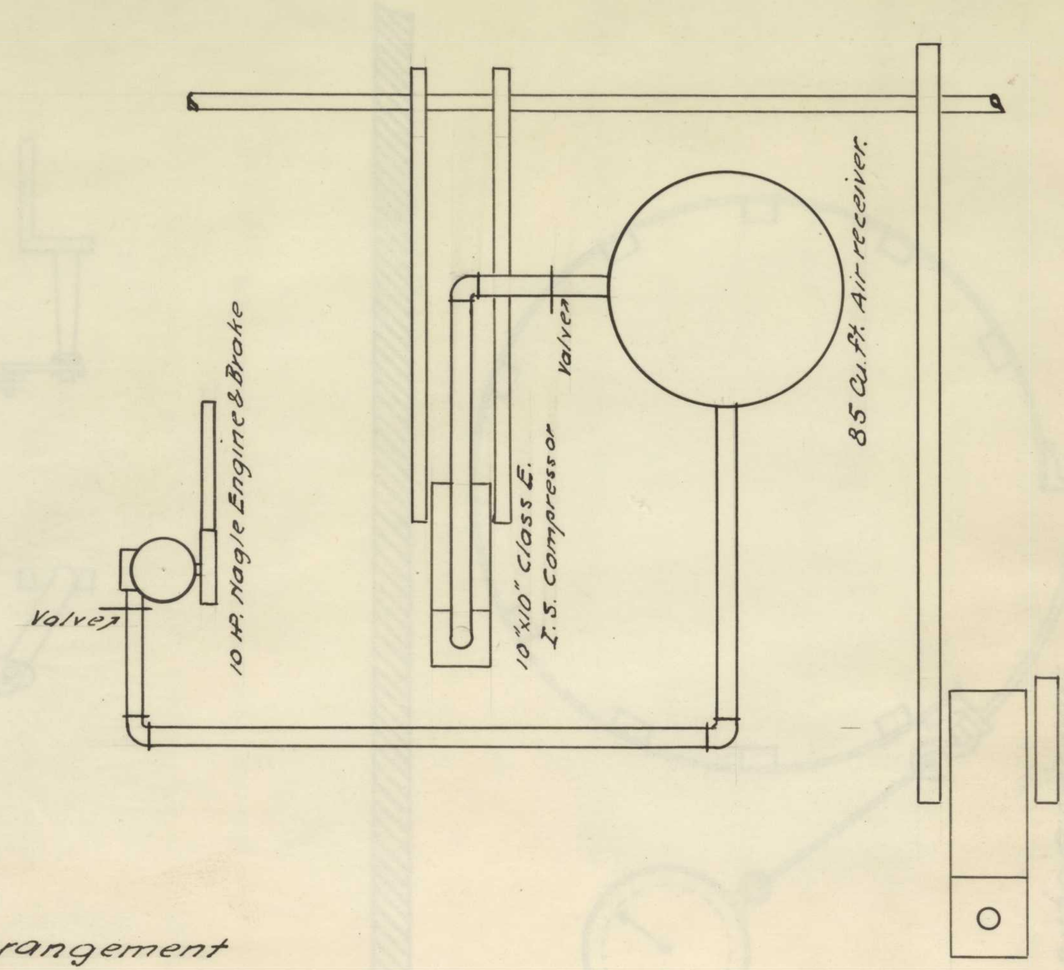


INGERSOLL-SERGEANT BELT DRIVEN AIR COMPRESSOR, CLASS "E."



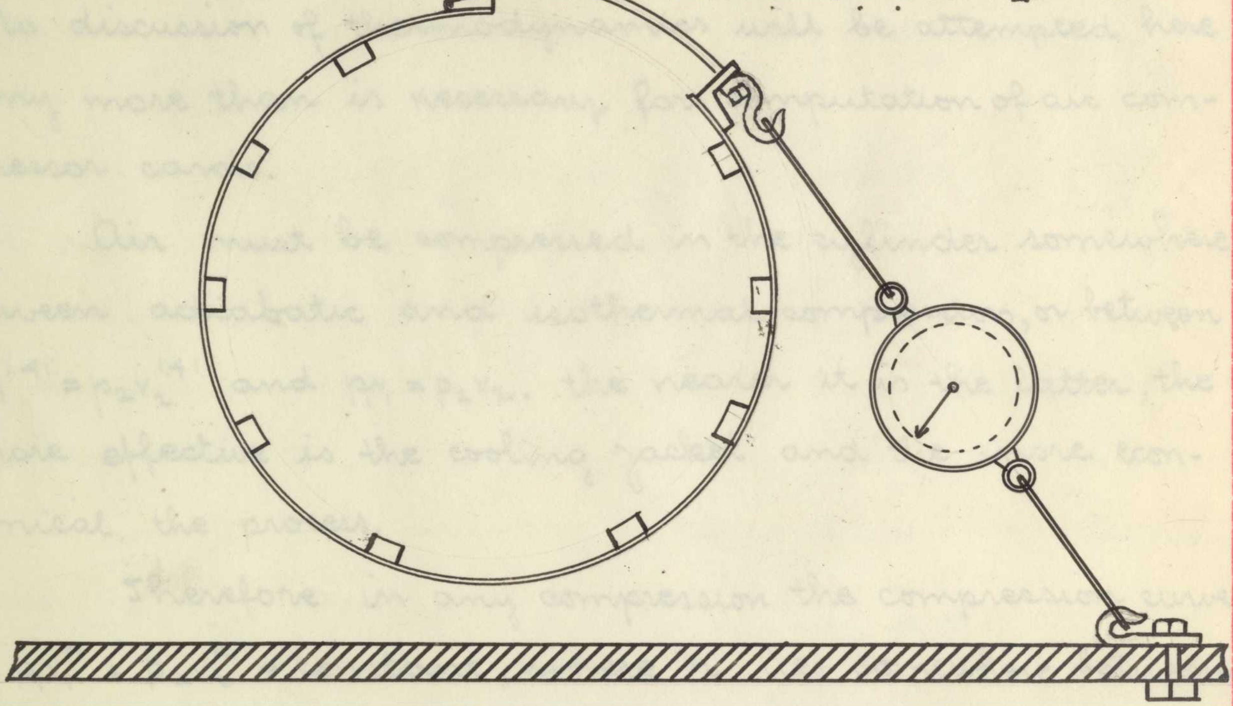
SECTIONAL VIEW OF AIR CYLINDER WITH VERTICAL LIFT VALVES.

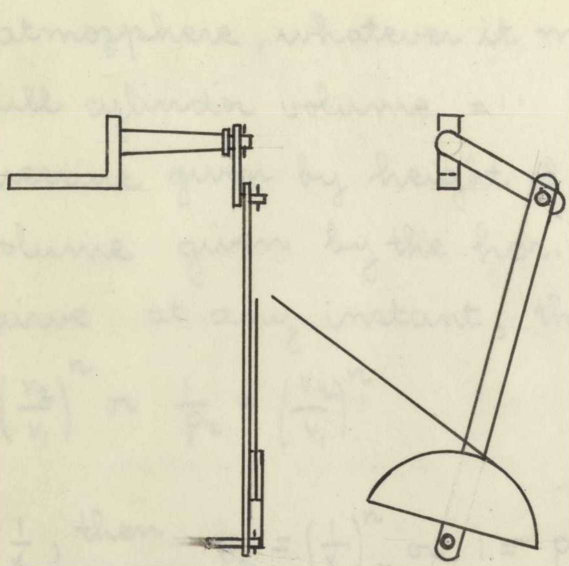
Used on compressors, Class "H," "J," "F" and "E."



Outline of the general arrangement of thesis apparatus. M.E. Lab. U. of I.

Brake for the Nagle Engine.
Steel Band $\frac{1}{4}'' \times 1\frac{1}{2}''$
Wooden Blocks $1\frac{1}{2}'' \times 1\frac{1}{2}''$.





Indicator Rig for Air Comp'sor.

Thermodynamics of Compressed Air.

No discussion of thermodynamics will be attempted here any more than is necessary for computation of air compressor cards.

Air must be compressed in the cylinder somewhere between adiabatic and isothermal compression, or between $p_1v_1^{1.41} = p_2v_2^{1.41}$ and $p_1v_1 = p_2v_2$. the nearer it is the latter, the more effective is the cooling jacket and the more economical the process.

Therefore in any compression the compression curve is $p_1v_1^n = p_2v_2^n$ = constant, where n lies somewhere between 1 and 1.41

From the indicator card at hand we have given

p_1 = 1 atmosphere, whatever it may be in certain locality.

v_1 = full cylinder volume = 1

p_2 = pressure given by height of the card times the spring.

v_2 = volume given by the hor. projection of the compression curve at any instant, then

$$\frac{p_1}{p_2} = \left(\frac{v_2}{v_1}\right)^n \text{ or } \frac{1}{p_2} = \left(\frac{v_2}{v_1}\right)^n$$

$$\frac{v_2}{v_1} = \frac{1}{x}, \text{ then } \frac{1}{p_2} = \left(\frac{1}{x}\right)^n \text{ or } 1 = p_2\left(\frac{1}{x}\right)^n = \frac{p_2}{x^n}$$

$$\therefore x^n = p_2 \text{ or } n = \frac{\log p_2}{\log x}$$, when p_2 is expressed in atm.

to use this formula it is, however, necessary to determine the percent of clearance in the cylinder in order to know the exact value of $\frac{v_2}{v_1}$. In this way exponent n can always be found and the nearer it is to unity the more efficient is the compression.

Multiple Cylinder Compression.

The work done in compressing air for p_1 to p_2 is (Peabody's thermodynamics) $p_1 v_1 \frac{n}{n-1}\left\{\left(\frac{p_2}{p_1}\right)^{\frac{n-1}{n}} - 1\right\}$, the work done by compressing the same volume in two cylinders is $p_1 v_1 \frac{n}{n-1}\left\{\left(\frac{p_2'}{p_1}\right)^{\frac{n-1}{n}} + \left(\frac{p_2}{p_2'}\right)^{\frac{n-1}{n}} - 2\right\}$, (and this becomes minimum when quantity in parenthesis becomes minimum) Now $\left(\frac{p_2}{p_1}\right)^{\frac{n-1}{n}} = \frac{T}{T_1}$ and it is evident that $\frac{T}{T_1}$ is greater than $\left(\frac{T'}{T_1} + \frac{T}{T_2'}\right)$ therefore multiple stage compression requires less work than single compression.

Expansion of air in compressed air engines.

It is safe to assume that expansion in compressed air engines takes place adiabatically, then expression for the work done per each stroke is $\frac{Gc}{A}(T_1 - T_2)$ where G is number of pounds of air used, c specific heat for constant volume, in the case of air $= .16847$; $\frac{1}{A} = 778$ foot pounds; and T_1 and T_2 initial and final temperature. Since G is the only unknown quantity in this equation, it is easily determined, knowing area of the card and such constants as dimensions of the cylinders and R.P.M.

The following are the most important articles bearing on compressed air that appeared in various engineering puplications up to 1899 and that the writer could collect. from various engineering indexes and other sources.

Flow of air in orifices of a thin plate, by A. Fliegner. Gives formula derived from experiments made with orifices from 3.17 to 11.36 mm. in diam. Van Nost. Eng. Mag. v. 25, p. 217.

Coefficient of friction of air flowing in pipes. W. C. Unwin.

Efficiency of air compressor practically considered. A paper of considerable value by Mr. Joseph Williams read before Inst. Marine Eng'rs. Mechanical World. March 28, 1891. pp. 124-5 et seq.

Efficiency of compressed air, by Prof. C. M. Woodward. A development of the fundamental equations, showing effects of jacketing and compounding. Jour. Assn. Eng. Soc. vol. 3, p. 101.

Flow of air through long pipes, by E. Stockalper. Gives details of experiments made at the St. Gothard tunnel. Van Nost. Eng. Mag. Vol. 24, p. 96.

Compressed air motor for tramways. A paper by D. S. Jacobus describing the railroads at Nantez and from Vincennes to Nogent, with records of tests etc., and estimating the cost of a line in the United States.

Trans. A. I. M. E. 1890. pp. 19.

Physiological effects of compressed air, by C. M. Woodward. Gives full account of all matters relating to the use of compressed air during the building of the St. Louis Bridge. Van. Nos. Eng. Mag. vol. 26, p. 29.

Results of experiments with compressed air made by order of the Italian Government at the Mt. Cenis tunnel. Van Nost. Eng. Mag. vol. 6, p. 63.

Hoists operated by compressed air adapted to warehouse purposes. A description of such an installation in Liverpool. Trans. Liverpool Eng. Soc. vol 6, p. 92-99.

Measurement of the velocity of air in pipes. Paper by Bryan Donkin before Inst. C.E. Comparison of values obtained by anemometers, measurements with actual velocities calculated from change in volume of a gas holder tank. Experiments in cast iron pipes 8" to 24" in diam. Eng. News. Dec. 22, 1892, pp 584-5.

Transmission of power by air. A paper by A. E. Chodzko. discussing compound air compressors. Am. Eng. & R.R. Jour. Aug. 1894.

A note on compressed air. A paper on the use of compressed air by Frank Richards read before the A.S.M.E. Vol. 15, 1894 p. 685.

Compressed air. Relative cost of compressed air and steam under different conditions. Am. Mach. Nov. 22, 1894.

Compressed air; its use for cold storage and cooling rooms in plants adapted to dwellings. Advocated by G.D. Hiscox. Sci. Am. Sup. Feb. 23, 1895.

Dredging with compressed air. The Moormann apparatus as used on the Weser river. The river bottom is loosened and the material driven upward by the air jet and carried away by the current. Eng. News. Jan. 17, 1895.

Stopping leaks by compressed air in lock foundations. Short article. Eng. News, May 10, 94.

Pneumatic storage. Handling grain by compressed air and storing it in steel tanks. Short ill. art. Sci. Am. Sup. March. 9, 1895.

Pneumatic interlocking. The plant at the New Boston Terminal of the Boston and Main R.R. Abstract containing essential details of paper by J.P. Coleman. Eng. News. June 13, 1895. p. 378

Pneumatic dispatch system. Wildermann system Illust. desc'tion of this system now in use in Berlin. Lond. Eng. Nov. 13, 1891, p. 577-8.

The pneumatic tube. System of the City Press Asso. of Chicago. Ill. art. by W.L. Stebbins. Eng. News. July 5, 1894

Pneumatic tube transmission. Extract from the annual report of the Post Master-General 1891. Gives brief history of the subject with quite full desc. of the Berlin system; also brief desc. of other systems. Ry. Rev.

Jan. 30. 1892, pp. 74-6.

Progress in pneumatic tube transmission. Advantages and requisites for success. Description of system at Paris, Berlin, Vienna and New York. Eng. Mag. Feb. 1893. p677-89

Pneumatic tube transmission. Description of the London system. Abstracted from the Engineer. Eng. Rec. Jan 16, 1892. p. 110.

Power transmission by compressed air. Notes of a lecture by Prof. Coleman Sellers before the Stevens Inst. desc'g various uses of compressed air and important plants. From Stevens Indicator. Eng. Rec. Aug. 13, 1892, p. 170-1.

Power transmission by compressed air and steam. Prof. W. C. Unwin. Lect. before Soc. of Arts. Oct 6, '93. Reprint in Eng. Rec. Nov. 11, 18, 25. 1893 et seq.

Transmission and distribution of power by compressed air. Abstract of paper by Prof. J. T. Nicholson before the Canadian Soc. of C. Engr's, investigating the theory and economy of this system of power transmission. Efficiency of compressors and motors and loss of power by transmission. Lond. Eng. July 7, 1893. p. 2.

Power transmission by compressed air. The plant of the North Star Mining Co. at Grass Valley Cal. using the largest Pelton wheel built for the air compression plant. Plans and details. Ill. fully. Eng. News. Dec. 19, 1895.

The use of compressed air in raising vessels. The S.S. Plymouth raised by this method by the aid of pontoons.

Eng. Rec. June 30, 1894.

Air distribution in Paris. Popp system. Ill. Eng. News. Dec. 14-28, 1889.

The Mekarski street tramway motor. Ill. Eng. News. May 24-31, 1889.

Street motor, Astoria, Long Isl. Eng. News. July 25, 1885.

Compressed air meter. The Engineer, Feb. 13, 1885.

Compressed air power supply at Birmingham. The Engineer Feb. 13, 1885.

Air compressing plant at Guinnesec Falls, Mich. Am. Engineer. Dec. 19, 1884.

Air liquefying. The Engineer. Jan. 29, 1886.

Compressed air. W. L. Saunders. Cass. Mag. June '92

Traction with compressed air (La traction à l'air comprimé) M. A. Monnerqué. A general account of the Mekarski system as employed in Paris since 1876. 5000 w. Rev. Gen. de Chemins de Fer. March 1900.

Discharge of air from pipes under heavy loss of pressure. Wm. Cox. A valuable mathematical discussion with numerous examples showing the practical applications of the methods of computation, also useful tables. Serial. Pt. 1. 1200 w. Comp. Air. Jan. 1900.

A liquid air plant. Ill. and desc. the plant of Ostergren & Berger, New York City; the machinery, process etc. 2000 w. Ice & Refrigerating Jour. Jan. 1900

Speed of air compressors. Frank Richards. A discuss'n of the proper speed of an air compressor written in reply to to an inquiry. 1300 w. Am. Mach. Feb. 8, 1900.

A practical consideration of compressed air. W. L. Saunders A lect. before the Frank. Inst. Ill. Jour. Frank. Inst. May 1892 Abstract in Eng. News, Aug 25, 1892. p. 175-7.

Apparatus for the compression of air for the Parisian Compressed Air Co. Ill. desc. of this large plant. From Le Genie Civil. Sci. Am. Sup. July 16, 1892 p. 13788-90.

Compound air compressors and motors. Paper by Prof. A. C. Elliot read before the South Wales Inst. Engrs. giving the theory and practical application. Lond. Eng. Dec. 4 '91 et seq.

Compressed air for distributing power plants. A desc. of the Riedler air compressors for the new power station at Quai de la Guare, Paris; details and dimensions. Tripple exp. eng's, high and low pressure air and steam cylinders. The Iron Age. Sept. 15, 92 p 468-71.

Compressed air for street cars. Art. by Gen. Hermann Haupt citing the advantages and economy of such a system of motive power based on a report by the author in 1879 on this question. Eng. Mag. Aug. 92 p. 617-22.

Mekarski compressed air tramway at Berne Switzerland used for street car line. Max. grade 5%. Air compressed at central station and charged in cylinder or car. Length of run @ 40 min. Said to be economical and give good satisfaction. Eng. News. Apr 20, 1893 p. 381.

The widening use of compressed air. Short desc. of a few of the modern applications of compressed air. Deep well pumps, pneumatic tubes for transmitting mail, refrigerating mach. etc. Eng. Mag. Nov. 93. p. 145-51.

Compressed air tramway in Berne Switzerland. Comp. air motors used on grades of 5%-6%. Water power used to compress air in accumulator to pressure of 440# to sq. in. Compressed air mixed with steam to keep at uniform temperature. Length of run-about four miles before recharging. Lond. Eng. Feb. 24, March 3, 1893, et seq.

About reheating compressed air. Frank Richards. Am. Mach. Feb. 28, 1895. 2000 w.

Calculation of a compressed air transmission when subsidiary losses are taken into account. From Prof. Unwin's "Development and transmission of power". Eng. Mech. Oct 4, 1895

Compressed air as used in mines. Abstract in Eng & Min. Jour. March 9, 1895. Chas. Hanson.

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Compressed air vs. electricity. Fr. Richards. Am. Mach. May 11, 1895. 1600 w.

A new air compressor. Ill. 1100 w. Eng. News. June 6, 1895.

A theory of the air lift pump. Ill. Elmo G. Harris. A mathematical analysis believed to be the first attempt at such a treatment of the theory of air lift pump, with tables of results. Jour. Frank. Inst. July 95. 3300 w.

Adiabatic curve construction. Uses of logarithmic section paper. Describes a method of drawing adiabatic curves whereby there seems to be a great saving of labor effected. Am. Mach. Aug. 1, 1895. 1600 w.

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Test of a compound air compressor. Gives data and computation of saving effected, with some general remarks upon stage compression as compared with single compression. Review of a graduate thesis by F.C. Weber and W.K. Lanman at Cornell university. Am. Mach. April 16. 1000 w. 1896.

A compressed air paradox. Fr. Richards. Effect of velocity upon friction of air in pipes is well discussed and a formula for computing the head for forcing air through pipes at different velocities is given. Am. Mach. April 16, 1896. 900 w.

High pressure air compressor of the pneumatic battery at Fort Winfield Scott, San Francisco, Cal. B.C. Batcheller.

Ill. desc. with data. An instructive article. Am. Mach. April 23, 96. 1800 w.

Compressed air as used for power purposes. F.C. Weber Lecture delivered before the engineering society of Columbia College Comp. Air. May 1896. 2000 w.

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Some compressed air victims. Frank Richards. Past failures in air propelled street cars and their causes. Am. Mach June 18, 1896. 1800 w.

The efficiency of air compressors. C.P. Paulding. Review of some points in articles which have recently appeared in Am. Mach. The possible and actual in air compressors. Am. Mach. July 9, 1896. 1200 w.

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Compressed air vs electricity. F.S. Watkins. Briefly compares the first cost, efficiency, cost of operation, reliability, and difficulties. 1000 w. Comp. Air. Feb. 1897.

Advantages of compressed air. Jas. E. Lewis. A very complete history of the progress of this power from the earliest recorded experiments to the present day, giving its numerous uses Ill. 7000 w. Canadian Mining Rev. Feb. 1897.

Fairness in comparing air and electric power. Editorial advising the partisans of each power to devote their energies to the selection of legitimate field and the development of the power in which they are interested. 1000 w. Ry. Rev. Feb. 27, 1897.

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Naval use of compressed air. F. W. Bartlett. Proposed extension of the use of compressed air on men-of-war. Suggests ways of using air and states why it is better for many purposes than either steam or electricity. 1700 w. Am. Mach. Feb. 18, 1897.

Pneumatic tubes. Locating obstructions in underground pneumatic tubes in Philadelphia. B. C. Batcheller. An interesting account of the efforts made, based on the velocity of sound waves, and the degree of success attained 1700 w. Eng. News. March 4, 1897.

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Snow flanger operated by compressed air. L.S.&M. R.R. Oscar Antz. Ill. detl. desc. 1500 w. Am. Eng'g & R.R. Jour. March 97.

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Theoretical methods of air compression. L.R. Hopton. A short outline of the various modes of compression with comparison of their efficiency and advantage. 1500 w. Yale Sci Month. March 1897.

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Painting freight cars by compressed air. C.E. Copp. Abst. of a rep. before the New Eng. R.R. Club. The result of a visit to Pittsburg for the purpose of investigating the subject 1000 w. R.R. Car Jour. March 1897.

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Cost of operating air cars in New York City. E.E. Pelter. A statement of the actual operating expenses for seven months throug extreme ranges of temperature. Ill. 2300 w. Comp. Air March '97

A pneumatic snow plow. Ill. desc. used on the Atlanta Consolidated Street Ry. Co. St. Ry. Rev. March 15, 1897.

Discussion of the Berlin tramway. An energetic disc'n before the German Ry. Soc. as to the merits of various systems of propulsion; electric overhead and underground and also compressed air. Ill. 6000 w. Glaser's Annalen March 1, 1897.

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Machine tools operated by means of compressed air Desc. in det'l. a device used on planing machines; the invention of Mr. A. Gordon of Hamilton, O. Sectional views. 1000 w. R.R. Gaz. April 30, 1897.

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Compressed air for street railway service. Experience. A criticizm of Gen. Haupt's assertions as published in the N. Y. Sun. 1200 w. Electrical Rev. Lond. Apr. 7, 1897.

The Köester Compound air compressor. A tandem compound steam engine and a tandem compound air compressor coupled side by side to the same shaft with cranks at right angles; the air cylinders have mechanically operated valves. Efficiency 81% 3500 w. Zeitsch. d. Ver. Deutsher Ing. April 10, 1897.

Relative efficiencies of a compressed air plants due to difference of level above and below sea level. F. C. Weber. Formula and chart by use of which one may select an air compressor of sufficient capacity to supply a motor with equivalent volume of air no matter where it may be located. 700 w. Comp. air. May 1897.

The use of compressed air for mining purposes. E. A. Rix A lecture to the engineering students of Leland Stanford jr. University. Considers compressed air the only power which is alone sufficient to supply all the power needs of an average mine. 2500 w. Min & Sci. Press. May 15, 1897. Serial.

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Compressed air locomotive for the Manhattan Elevated railroad. Brief ill. desc'n. 350 w. Am. Mach. May 6, 1897.

Hardie compressed air locomotive for the Manhattan El. railroad; Ill. desc'n. 800 w. R.R. Gazette. May 21, 1897.

High pressure air compressor and receiver for the Hardie locomotive. Views and desc'n. 800 w. Am. Mach. June 10, 1897.

Hydraulic air compressing plant. C.H. Taylor. Extract from a paper read at the meeting of Mining Engineers in Montreal. The compression was effected by the flow of water down a vertical pipe; the air being collected in a receiver. Ill. 2400 w. Eng., Lond. June 11, 1897.

Notes on air compressors. Robert Peele. An article intended particularly for the use of students in mining engineering. Part first treats of the general structure of compressors, the compression of air, wet compressors, dry compressors, piston clearance in air cylinders and compound compression Ill. 8500 w. Sch. of Mines Quarterly. Apr. '97. Serial.

The Philadelphia compound air compressor. Ill. desc. of the principal features of the new compound air compressor built by the Phila. Eng'g. W'ks. 1800 w. Iron Age. June 17, 1897.

The use of compressed air at high altitudes. W. W. Pullen. A few notes on the results of the application of the air compressor at high altitudes. 1200 w. Practical Engineer May 28, 1897.

Compressed and liquefied. L. L. Summers. A consideration of the application and elementary principles of physics to this subject, and the prospect of increasing economy of compression. 1800 w. Elec. Engineering July 1, 1897.

The use of compressed air for mining purposes. E. A. Rix. A lect. delivered to the eng'g students of the Leland Stanford, jr. University. Considers the proper conditions under which to compress and use air, and the requirements of a modern air compressor and motor: This is the system which alone is sufficient to supply all the power needed by an average mine. 8500 w. Elec. Engineering. June 15, 1897.

Experiments on a two stage air compressor. J. Goodman. Contributed to the Inst of Civ. Eng'rs; devoted to a description of tests and methods of reducing the results. Ill. 3200 w. Colliery Guardian, July 23, 1897.

Compression of air by direct action of water. H. W. Umney Presents an improved method of compressing air suitable for adoption in the case of low water falls, and of less expense than by any other means. 3300 w. Practical Engineer July 16, '97.

Compressed air explosions caused by ignition. A letter of inquiry and editorial reply. 1400 w. Comp. Air. July 1897.

Power of portable compressed air. Fr. Richards; use and cost of compressed air as a motive power. 1700 w. Am. Mach. July 29, 1897.

Uses of compressed air J. C. Ransom. Reviews the development of the past few years and future posiblities. 2200 w. Tradesman. July 15, 1897.

Liquid air as a factor in electrical development. Elihu Thompson in the Boston Herald; outlines a system worthy of examination by those interested in electrical development 1000 w. Elect. Eng. July 22, 1897.

Electric haulage at Port Chalmette G.F.P. Account of the adoption of electricity in the place of compressed air and claiming greater economy. Also editorial objecting to conclusions and defending the compressed air. 2000 w. R.R. Gaz. July 9, 1897.

Some practical examples of the use of compressed air in machine shops; a belt shifter, center grinder, bolt cutter. Ill. desc. of above appliances. Am. Mach. Oct, 15, 1896. 800 w.

An air hoist for mercantile purposes. Ill., del., desc. Comp. Air. Oct, 1896. 600 w.

Air volumes used in engines. Formulæ & data. Comp. Air. Oct. 1896 400 w.

Application of compressed air to cranes and hoists. Wm. Prelevitz. Ill. des'n of a 20 ton travelling crane driven by compressed air. Comp. Air. Oct. 1896. 1200 w.

The cost of air compression. Fr. Richards. How it should be reckoned in the most improved compressors. Am. Mach. Oct. 22, 1896. 1000 w.

Compressed air and its economies in foundries. C.W. Shields. Paper read before Sept. meet. of Western Foundrymens Asso. Foundry. Sept, 1896. 3300 w.

The compressed air power plant at Jerome Park, N.Y. Ill. desc. Comp. Air. Sept, 1896. 1400 w.

Compressed air as a hoisting power in the foundry. Geo. A. True. Read before the West. Foundrymen's Ass. Desc. of plant required for a foundry of 30 tons daily output; del. ill. and gen. review of advantages of such an installation in foundry work. 3600 w. Iron Age. Sept. 24, 1896.

Trial of the compressed air motor by the Third Ave. Railroad Co. N.Y. Desc. of motor with cuts, and an account of some experiments. Sc. Am. Aug. 15, 1896. 1000 w.

Flow of compressed air in pipes. Wm. Cox. An adoptation of D'Arcy's formula for flow of water in pipes to make it applicable to any other fluid is thought by the writer preferable for compressed air. The modified formula is presented and discussed Am. Mach. Aug. 20, 1896. 800 w.

Flow of compressed air in pipes. F. A. Halsey. A determination of the value of the constant in Cox's fluid flow computer, and a comparison of results with those obtained by D'Arcy's formula, showing that the computer is sufficiently accurate for most practical purposes. Am. Mach. Aug. 27, 1896. 1000 w.

The rise of the young giant, compressed air. Ill. C. W. Shields. Reviewing the ever increasing applications of compressed air as a motive power. Eng. Mag. Jan. 1897. 4300 w.

Compressed air; its generation, transmission and application, with special reference to its use in railroad shops. C. W. Shields. Presents in a brief form some of the more important facts concerning the methods of generating, laws governing air compression etc. Illustrations and discussions N.Y. R.R. Club.

Nov. 19, 1897. 15500 w.

A light ship compressed air plant. Ill. desc. of plant on lightship #42. 1200 w. Am. Mach. Dec. 17, 1897.

Some of the uses and advantages of compressed air. J. H. McConnell; read before the Western Railway Club. Ry. Rev. Dec. 19, 1897. 2300 w.

Compressed air in railway work. Wm. S. Aldrich. Reviews its application to street railway work, mine haulage, motive power etc. Considers a combined system for street railway work desirable. Am. Electrician. Dec. 96. 2800 w.

Economy in compressed air. C. W. Shields. Comparison between air pumps and compressors, with use and advantages with use and advantages of compressors. Eng'g Mech. Dec. 1896. 1800 w.

Compressed air recoil cylinders for heavy mortars. Ill. desc. of design by H. A. Spiller. Sci. Am. Jan 2, 97. 600 w.

Compressed air for hoisting purposes. J. J. Klindworth Machinery. Jan. 1897. 1400 w.

Compressed air for city and suburban traction. H. Haupt. Presents the subject of air motors briefly stating some of the properties of air and the laws that govern its compression, expansion and distribution, also such properties of steam as enter into the consideration of the questions at issue. Jour. Frank. Inst. Jan. 1897 Serial. 1st pt. 4500 w.

The best air compressor for shop service. Fr. Richards. A criticism of some ideas advanced in the discussion of compressed air at the monthly meeting of the R.R. club, with the writer's personal opinions. Am. Mach. Dec 3. 1897. 1500 w.

Cost and profit of compressed air. Quotations from papers of G. A. True and C. W. Shields read before the West. Foundrymen's Ass'n. which are strong arguments for compressed air. Ry. Mast. Mech. Dec. 1897. 2500 w.

Doubling the efficiency of compressed air. Fr. Richards. Presents a scheme for the more economical use of comp. air. 1800 w. A. Mach. March 24, 1898.

Compressed air at the Gwin Mine. E. A. Rix. From the Golden Jubilee edition of "The mineral resources of Calaveras County", Cal. Ill. and describes an interesting and economical installation. 1700 w. Jour. of Elec. Feb. 1898

Analysis of air compressor indicator cards. 1600 w. Am. Mach. March 3, 1898.

Shop tools driven by compressed air. Am. mach. March 24, 1898 Serial, 1st part.

The Boyer Hammer. Ill. desc. 4000 w. Engineering. Feb. 25, 1898.

Compressed air in a rolling mill. H. M. Perry. Ill. desc. of some of the applications at the Passaic Rolling Mill Co. of Patterson, N. J. 1000 w. Comp. Air. March, 1898.

Compression of air by direct action of water.

H. W. Unney. Deals with an improved method of compressing air, illustrating experimental and stating the advantages of the method. 3000 w. Ry. & Eng'g Rev. Sept 17, 1898.

Compressed air plant at Ainsworth B.C. Desc. and ill. an apparatus for compressing air directly by falling water without the use of any moving mechanism. 1200 w. Can. Elec. News. Sept. 1898.

Liquid air. Geo. H. Barker. A lecture at the Friends Inst. Lyceum. Phila. Serial. Sc. Am. Sup. Sept 24, 1898

Liquid air, its production and properties S. A. Tucker. 5500 w. School of Mines Quart. July 1898.

Compressed air plant in the locomotive works at Leinhausen near Hanover. An extensive and interesting plant. 3000 w. Ill. Glaser's Annalen. Aug. 1, 1898.

Device for reheating comp. air in pumps. Ill. E. A. Rix 1000 w. Mod. Mach. July 98. Collier Guard. Aug. 26, 1898.

Experiments with compressed air in ship building and ship-yard work. Wm. Burbingham. Interesting particulars of work done by pneumatic machines. Ill. 2500 w. Marine Eng. Sept, 1898.

Practical application of high range compressed air power transmission. Fr. Richards. Desc. the machine and the system by which the compressor receives the air returning from whatever it is employed to drive, and compress it to still higher pressure sending it out again to do more work. Ill. 1800 w. Am. Mach. Apr. 28, 1898.

The proportions of compressed air compound cylinders to secure best economy. Economy of compounding. F.A. Halsey. Demonstrates that the proportion of cylinders which divides the work equally, also secures the greatest saving possible from compounding. 1500 w. A. Mach. Mar. 31, 1898.

Liquid air, W.H. Dickerson. Remarks on conditions necessary for reducing gases to the liquid state, with explan. of the process of Chas. E. Tripler and descn of experiments. 4800 w. Stevens Idic. Apr. 98.

Liquefied air. S. D. Benoliel. Gives an account of the work of Chas. Tripler with references to the patents of Dr. C. Linde, W. Hampson, and describes investigation and properties. 1800 w. Elec. Eng. N.Y. April 14, 1898.

Liquid air. W.C. Peckham. Describes three methods of measuring low temperatures, giving experiments. 1200 w. Sc. Am. April 13, 1898.

Liquid air as a blasting explosive. J.A. Ewing. Extract from a paper read before the Soc. of Arts, London on Linde's method of producing extreme cold and liquefied air. Refers to its use as explosive by mixing it with carbon. Ill. 1800 w. Colliery Guard. March 18, 1898.

The commercial manufacture of liquid air. An account of the methods by which liquid air is now manufactured with ordinary commercial apparatus and at a comparatively small cost. Desc. apparatus used by Tripler. Also editorial. 4000 w. Eng. News. Apr. 14, 1898

Pneumatic machinery for loading and discharging grain cargoes. F. E. Duckham. Read at the meeting of Inst. of Naval Archts. London. Ill. desc. of pneumatic elevators now in successful operation. 1700 w. Engr. Lond. April. 8, '98.

Mechanical refrigeration by use of compressed air. Leicester Allen. A clear explanation of the mode of coolind by compressed air, and the cause of failure from wrong application. Covers the entire cycle of operations and changes in the process. 3000 w. Am. Mach. April 21, 1898.

Air compressors at high altitudes. F. A. Halsey. Shows that the air produced is not proportional to barometric pressure, and the value of compound compression in such cases. 1300 w. Am. Mach. June 2, 1898.

Diagrams for compressed air; horse power and temp. J. E. Johnson, jr. Diagrams plotted to supply quick and convenient means of obtaining fairly accurate solutions of these two questions in connection with compressed air. 2000 w. Am. Mach. June 23, 1898.

Compressed air motors. Describes in detail the distinctive feature of the Hoadley-Knight system of street railway operation. Ill. 2800 w. Comp. Air. May, June, 1898.

Constant pressure air receivers. E. A. Rix. Describes a way to overcome volumetric loss. It consists of having a pipe connected at the lowest point of the receiver and with a water tank high enough to give a const pressure. 1200 w. Am. Mach. July 7, 1898.

A simple air compressor. C.P. Turner. Ill. desc'n of a hydraulic air compressor. 1900 w. Mining & Sci. Press. July 2, 1898.

Liquefied air for industrial purposes. From La nature. Ill. desc. of Dr. Linde's apparatus which produces about 28 oz. of liquid air per hour with an expenditure of 3 HP to actuate the pumps. 1000 w. Sc. Am. Sup. July 2, 1898.

A topical discussion upon electrical, pneumatic, and mechanical power transmission in manuf. establishments. Ill. 12000 w. Jour. Western Soc. Engrs. June, 1898.

The Strand air compressor at the Maybach Mine Ill. desc. of double cylinder tandem air compressor with Corliss valves on air cylinders. Full details are given together with indicator diagrams. 2000 w. Glückauf. July 30, 1898.

Compressed air mine loco. Iron & Coal Trades Rev. Aug. 5, 1898.

Recent progress in the development of the pneumatic dispatch tubes. B.C. Batcheller. Brief reference is made to European systems, showing progress to 1893. An account of the 6" tubes in Philadelphia and 8" tubes in New York with an explanation of the theory. Ill. 6500 w. Jour. Frank. Inst. Aug. 1898.

Sand blast process. Ill. and describes the application of the sand blast to the cleaning of stone walls from smoke stains after a fire. Compressed air. Aug. 1898.

Recent Science. P. Kropotkin. Progress made in liquefying gases and air, motive power and transmission 9800 w. 19th cent. Aug. 98.

Tests of a King-Reidler air compressor at the Rose deep mine So. Africa. L. I. Seymour. Data of tests made with summary of results, and explanatory remarks 1500 w. Compr. Air. Aug. 1898.

Compressed air explosions. A recent typical explosion. Fr. Richards. Considers the dangers from imperfect desgn. and management. 1500 w. Am. Mach. Feb. 3, 1898.

Explosions in air compressors and receivers. T. G. Lees. Abstract of a paper read at meeting in Sheffield, Eng. Desc's and explains an explosion, which occured in Clifton Colliery, the conditions which caused them, and gives lessons to be learned. 2400 w. Ir. and Coal Trades Rev. Feb. 11, 1898.

Useful compressed air formulas. W. L. Saunders. Gives rules and formulas used by the writer in the application of compr. air. 1000 w. Compr. Air. Feb. 1898.

Compressed air haulage at Buck Mountain Colliery. T. D. Jones. Read at the annual meeting of the Assn. Describes the plant and its operation, giving comparative costs. 1500 w. Anth. Coal Operat. Ass. May 1898.

Experiments with liquified air. Brief desc'tion of the work done by C. Tripler and some experiments with the liquid. Ill. 2000 w. Compr. Air. April 1898.

The power value of liquid air. Fr. Richards. Discusses briefly what use to make of this peculiar product, showing that it is not at present to be of much value for power and for refrigeration. 1000 w. Am. Mach. May 28, 1898.

Use of compressed air in mines. M. Mortier. A review of the question wheter compr. air has been turned to its fullest account as regards useful effect or whether variations may be introduced with advantage into the method of its utilization. A summing up of the principles of this branch of mechanics. 4000 w. Colliery Guardian. Jan 22, 1897.

Compressed air motor on the elev. railroads in New York Ill. desc. of the experimental motor soon to be placed on the elevated roads, which with comments and explanation of system 1300 w. Sci. Am. Jan. 30, 1897.

Compressed air refrigeration. Fr. Richards. Describes with comment a plant employing compressed air for refrigeration. 1200 w. Am. Mach. Jan. 21, 1897.

Use of compr. on a great work. Describes the service to which this power is put in the construction of the Jerome Park Reservoir for the water supply of New York. 1500 w. Mfrs. Rec. Jan. 15, 1897.

Use of compressed air. Discussion at the Western Ry. Club. Dec. meet'g. of Mr. Mc Connell's paper read at the Nov. meet'g. 6500 w. R.R. Gaz. Jan. 15, 1897.

Test of a modern air compressing plant at the Long Tunnell Gold Mine, Walhalla. E. J. Rigby. Gives results of a test for economy and efficiency and shows that large savings may be effected by a proper use of air after compression. Ill. 4400 w. Trans. Aust. Inst. of Mining Eng'rs. vol 5.

A gasoline air compressor for bridge work. Ill. & desc. portable plant for generating compr. air. used in connection with work at West Point, Ky. in strengthening a bridge on I. C. R. R. 1100 w. Ry. Age. Oct. 14, 1898.

What is the efficiency of an air compressor? Fr. Richards. A discussion of the subject of compression showing the fallacy of some ideas generally held. 1400 w. Am. Mach. Oct. 6, 1898.

A pneumatic car journal turner. Ill. and desc's a machine that enables car journals to be turned on the repair tracks. 400 w. R.R. Gaz. Oct. 14, 1898.

Recent experiments in tamping track by C. A. F. R. Coates Read before the New Eng. Roadmasters' Ass'n., Boston. Remarks on the lack of progress made in surfacing track, and reviews some recent work in the use of the air blast. 3300 w. Comp. Air. Oct, 1898.

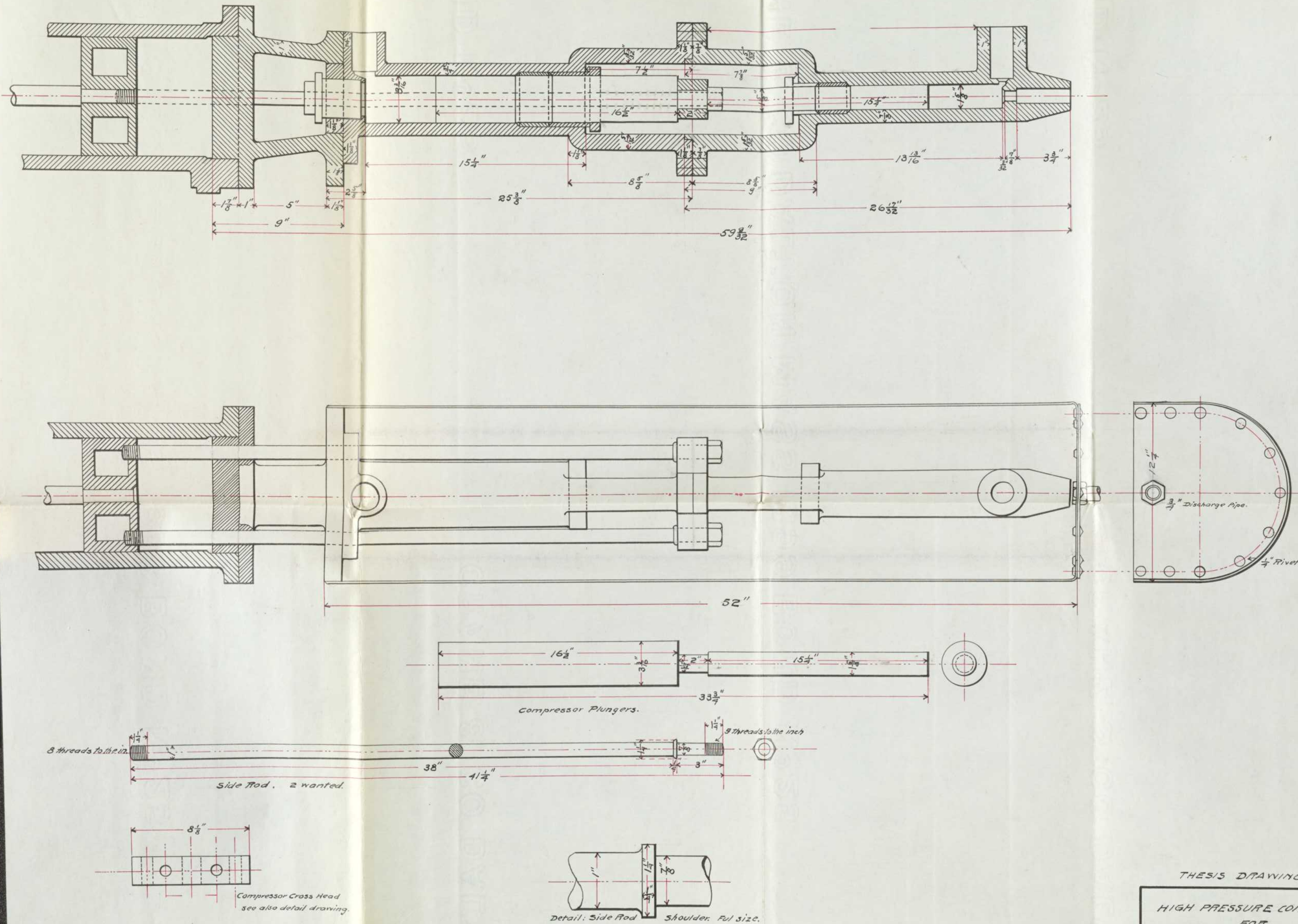
The Indexes reviewed are:

General Index to Engineering News.

Descriptive Index of Current Engineering Literature.

The Engineering Index.

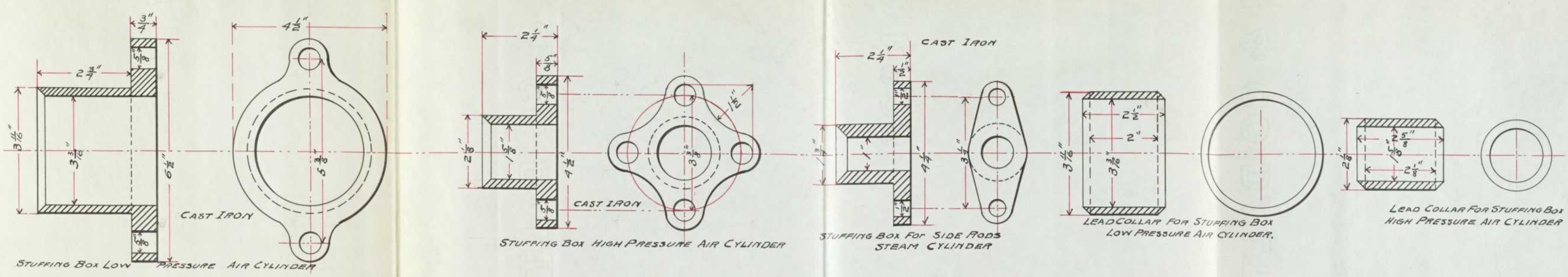
Galloupe's General Index to Engineering Periodicals

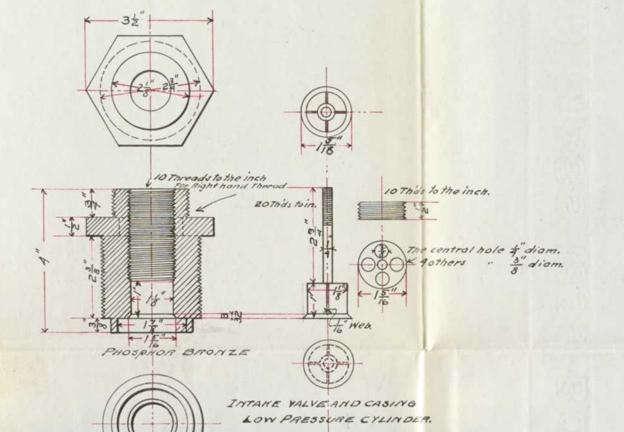


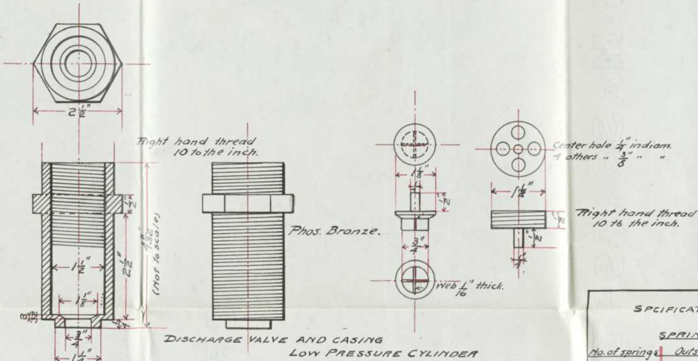
THESIS DRAWING

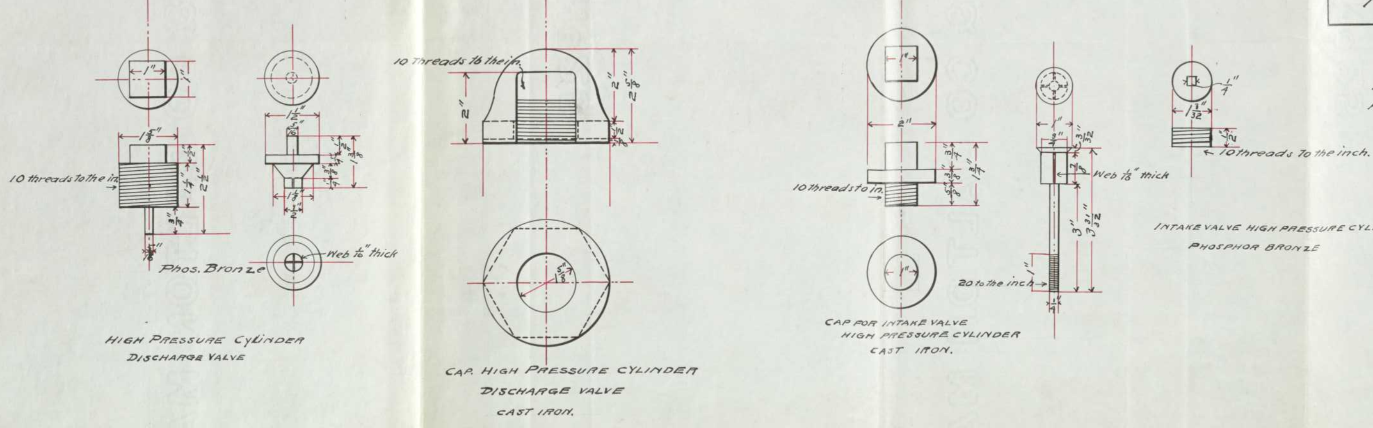
HIGH PRESSURE COMPRESSOR
FOR
M.E. LABORATORY
U. OF I.
GENERAL ARRANGEMENT & DETAILS.
SCALE 1/4 & 1/2 SIZE.

S. Dowriatt **58 D** April 12, 190









SPECIFICATIONS FOR VALVE SPRINGS.

SPRING STEEL THROUGHOUT.

No. of springs	Outside diam.	Diam. steel	No. of turns	Pitch
For low pressure intake valve				
1	1"	.12"	3	1/4"
For low pressure discharge valve.				
1	1"	.18"	4	3/10"
For high pressure intake valve.				
1	7/8"	.18"	3	3/10"
For high pressure discharge valve				
1	1 1/2"	5/16"	4	5/8"

General Directions

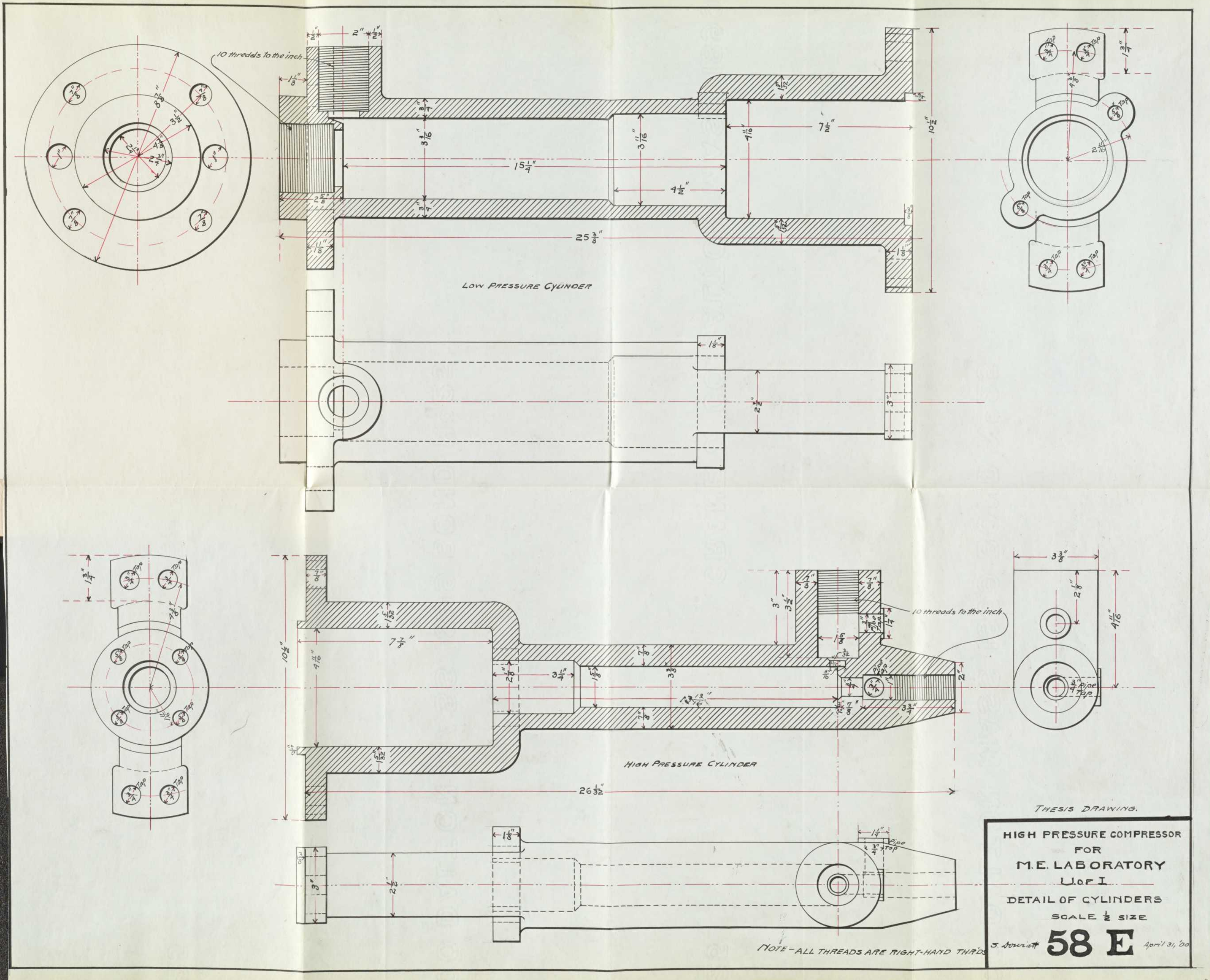
All threads are Right-hand threads.
All threads in cast iron are 10 to the inch
All threads in phos. bronze are 10 to the inch except 2 intake 1/4" valve stems which are 20 to the inch.

THESIS DRAWING.

HIGH PRESSURE COMPRESSOR
FOR
M.E. LABORATORY
U. of I.

VALVES, STUFFING BOXES, SPRINGS
SCALE 1/2 SIZE

E. Dowiatt **58 F** April 2, 1900


10 threads to the inch
LOW PRESSURE CYLINDER
HIGH PRESSURE CYLINDER
10 threads to the inch
THESIS DRAWING.
HIGH PRESSURE COMPRESSOR
FOR
M.E. LABORATORY
U. OF I.
DETAIL OF CYLINDERS
SCALE ½ SIZE
58 E
J. Louriatt
April 31, '00
NOTE - ALL THREADS ARE RIGHT-HAND THR'DS